Week 3 – Intro to Hydrothermal Activity and Event Plumes (aka Megaplumes) from Submarine Eruptions

Hydrothermal Processes overview
  - General comments
  - vent types: Focused flow, diffuse flow
  - chronic plumes over actively venting areas

Event Plumes
  - what are they?
  - association with eruptions

Note: hydrothermal effluent chemistry also changes in response to eruptions but this is not part of today’s discussion

Effects of hydrothermal activity on the ocean
  - Source of heat
  - Source of new dissolved chemicals
  - Source of gasses
  - Source of particles
  - Source of microbes
  - Supports chemosynthetic communities
  - Helps to disperse organisms
  - Metal rich sediments
  - Other chemicals are lost from sea water in the reaction zone of hydrothermal systems.
Global distribution of submarine hydrothermal vent sites (above) and areas of survey coverage (right), Baker and German, 2004.

Many of these sites are known from water chemistry in hydrothermal plumes above the sea floor rather than observations on the vents themselves.

Remember from lecture 2

- Rising, buoyant plume
- Seawater entrainment
- Cold seawater downflow
- Chimney
- Neutrally Buoyant, spreading, diluting plume
- Ambient current

Deep heat source temporally stable for years to decades or more
Oxidizing Environment

Particles form from solubility shifts from new temperature and redox state

Reducing Environment

Deep heat source temporally stable for years to decades or more; but, punctuated during and just after eruptions

Reducing

Immature black smoker chimney with little colonization (years old?) – SEPR 1999

nascent chimney systems

black smoker a few months after eruption – intense focused flow but no edifice (EPR 1991)
Riftia tubeworms at an established chimney system

Extinct chimney with new lava around it and a previously deployed temperature probe (9 50N EPR, 2006).

diffuse flow

Colonization experiments at a diffuse flow vent site (N-EPR)
Areas of active hydrothermal venting produce “chronic” plumes a few 10s to 100m above the sea bed containing...

Excess heat

Excess gasses (He, Rn, CH4, CO2)

Particles (Fe-sulfides, Fe-oxides, microbes)

Hydrothermal fluids mix rapidly with seawater. Entrainment of ambient seawater dilutes the rising plume and causes temperatures and particle concentrations within the plume to decrease within a short distance from a vent orifice. Hydrothermal plumes continue to rise through seawater as long as plume fluids are less dense (more buoyant) than the surrounding seawater. Once the density of the hydrothermal plume matches the density of the ambient seawater, the hydrothermal plume stops rising and begins to disperse laterally. This "neutrally buoyant plume" gets distributed by being "blown" by ocean currents at that density level.

Source: NOAA Vents website
hydrothermal plumes are likely to be very important for the transport and distribution of marine organisms, especially thermophile or hyperthermophile bacteria that live under the seafloor and have been released into the ocean in plumes resulting from recent volcanic events such as at CoAxial Segment, Axial Volcano and the Gorda Ridge.

Transient chemical effects in plumes

• Dilution of conservative constituents from dispersal (e.g., salinity, He) 

(conservative means no chemical reactions during mixing)

• Cooling from seawater entrainment

• Reactive particle formation (especially Fe-rich)

• Scavenging of particle reactive metals and oxyanions from sea water

• Microbial oxidation of reduced gasses (e.g., CH4, H2)

• Organic matter transformations

• Some tracers change at different rates and some roughly track each other (like 3He/heat)

I can suggest references if you are interested in this topic.
Plume Physics - The analogy to processes in subaerial volcanic eruption columns is useful to consider (this slide borrowed and rearranged from I. Skilling, Penn State)

Some hydrothermal plume observations and model simulations

3-d rendering of the TAG hydrothermal mound (MAR)

http://www.pmel.noaa.gov/vents/modeling/

Usually several tens of ms to perhaps a couple of hundred m above the sea bed
Some hydrothermal plume observations and model simulations

Vertical Geochemical Transport

http://www.pmel.noaa.gov/vents/modeling/

Event Plumes, aka Megaplumes

Larger, transient features formed in response to eruptions and perhaps other catastrophic events at one place or another on the sea floor.

2 diagnostic features: lots of particles and larger temperature anomalies than chronic plumes. **Can rise to 1km above the sea floor.**

Mid-ocean ridge plumes typically have maximum anomalies of 0.02-0.1°C, although event plume anomalies of up to 0.3°C have been observed (e.g., Baker et al. 1987).

Seamounts can have anomalies in excess of 0.5°C
By calculating the hydrothermal heat inventory (Q) for a 1-meter wide transect along the North Cleft segment from 1986 to 1997 we get another measure of the evolution of this hydrothermal system with time after the volcanic eruption. We see that the largest heat inventory was in 1986, followed by a sharp decline in 1987/88, a secondary peak in 1989/90, and continued relatively low levels through 1997.

Surveying for Chronic Plumes and Megaplumes

The CTD is towed behind the ship while being cycled through the bottom 200 meters or so of water where the hydrothermal plumes are located.
In 1986, a large plume of hot, particle laden water approximately one million cubic meters in volume was discovered over the North Cleft segment of the Juan de Fuca Ridge. This plume was unique in its shape (horizontally and vertically symmetric), size (100 km$^3$) and rise height (~1km), indicating that an enormous volume of hot water had been released in a relatively short period of time.

![Diagram of Cleft, 1986](http://www.pmel.noaa.gov/vents/PlumeStudies/)  

**JdFR 1986**

Fresh looking pillow lavas discovered after the megaplume

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![Diagram of Loihi, 1996](http://www.pmel.noaa.gov/vents/PlumeStudies/)  

**Loihi 1996**
Intense hydrothermal plumes from the 1996 Loihi seismic event had temperature anomalies of 0.5°C during the rapid response cruise around the summit at depths of 1050-1250m, with anomalies of 0.1°C at distances >8 km.

One surprise was the observation of a very intense plume at 1600-1800 m depth at a “background” station 50 km NNE of Loihi. A marked decrease in pH (0.2 units) and a remarkable 3He enrichment (150%) were measured, suggesting an injection of magmatic gasses to the water column during a large short-lived, but rapidly cooled, volcanic episode well below the summit of Loihi during the early stages of the seismic event. Source: HCV website

Towed hydrocast (tow-yo) at NW Rota #1 Submarine Volcano (14° 36' N) on February 12, 2003. A) Bathymetric map with tow line of hydrocast in white. B) Hydrothermal plume above volcano as delineated by optical backscatter. The black saw tooth pattern is the track of the CTD-rosette package as it passed over the volcano. The stair step features in the track are the locations where samples were taken. \( \Delta NTU \) = nepelometric turbidity units above ambient seawater.

http://www.oceanexplorer.noaa.gov/explorations/06fire/background/plumes/plumes.html
Some hydrothermal plume model simulations

1996 Gorda event plume

http://www.pmel.noaa.gov/vents/modeling/

 Usually hundreds of m above the sea bed but can be a km

Megaplane-eruption linkage

Dziak et al, 2007

Juan de Fuca and Gorda Ridge map showing location and date of significant earthquake swarms (seafloor spreading events) detected by the SOSUS system.

All swarms had either a response cruise that investigated the site or pre-swarm in-situ instrumentation. Inset diagram shows cartoon of event and chronic plumes released from a mid-ocean ridge.
**Relationship of earthquake migration rate (m-s-1) to onset of migration (hours after beginning of swarm).**

Logarithmic decay curve illustrates apparent non-linear relationship, dashed line shows 95% confidence interval derived from the model. The subaerial 1979 Krafla (Iceland) dike injection event (23) added for comparison. Dziak et al., 2007

Earthquake swarms associated with seafloor eruptions, fluid-temperature changes, or megaplume events are shown as stars; swarms with no clear magmatic activity or megaplumes are circles.

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**Another interesting aspect of megaplume formation:** injection of low solubility/high volatility metals and metalloids into sea water

Metal Partitioning During Hydrothermal Processes

- **soluble metals**
  - alkalis, alkaline earths (except Mg)
  - REE

- **non-soluble metals**
  - main group metals (III-V), transition metals, REE

Metal Partitioning During Eruptions

- **volatile metals**
  - main group metals (III-V), transition metals

- **non-volatile metals**
  - alkalis, alkaline earths, REE

Rubin, 1997, GCA
"Volcanic Vapor" 

Magmatic Temperature 

- element in magma 
- vapor-rock exchange 
- water-rock exchange 

Sub-Solidus Temperature 

- element in vapor phase 
- degassing effluent 
- magmatic fluid "picked up" by hydrothermal flow 

- condensation into cracks/vesicles 
- condensate exchange 

- water-condensate exchange 

- element in near-volcanic water mass 

- water-particle exchange 

- element in suspended particulate 

- element in sea water 

“Hydrothermal” 

Rubin, 1997

Crustal processes

Water column processes

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Oceanic Residence Time (yrs)

- less volatile 
- more volatile 

- CLASSIFICATION 
  - non-volatile/insoluble 
  - Adsorbed to Particulates

- PHASE ASSOCIATION 
  - NON-Degassing Signature

- SOURCE 
  - NON-Degassing Signature

- CLASSIFICATION 
  - more volatile 
  - VOLATILE/INSOLUBLE 

- PHASE ASSOCIATION 
  - Dissolved in Seawater

- SOURCE 
  - Degassing Signature

degassing efficiency: $\varepsilon_X$ 

element affinity matrix

Rubin, 1997
Ridge Fluxes

Log flux (g/yr)

Ca Na Mn Zn Rb Cu K Fe Li Ba B Sr Bi Al Pb As Cd Ag Sn Ni V La Ir Hg Ti Hf W Th Mg

element

- hydrothermal
- direct degassing

Rubin, 1997